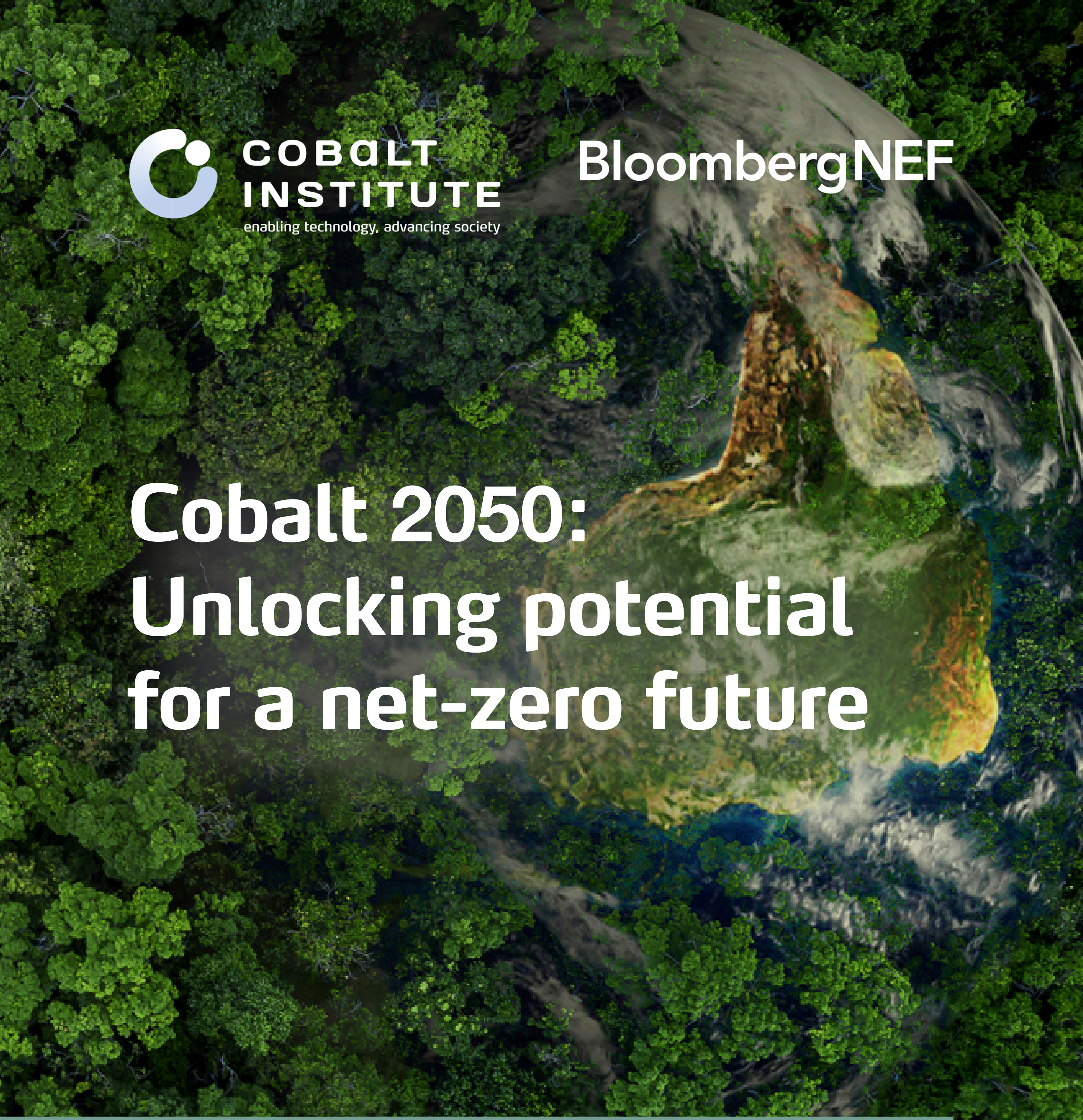


Cobalt Institute — enabling technology, advancing society

BloombergNEF

Cobalt 2050: Unlocking potential for a net-zero future

October 2024

CONTENTS

1. 10 KEY HIGHLIGHTS

1. Cobalt is indispensable for the world to reach net-zero by 2050 due to its use in electric vehicle (EV) batteries and its role as an enabler of new technology. Key sectors – EVs, aerospace, defence and consumer electronics – demonstrate significant growth in demand for cobalt between now and 2050.

2. Despite current market headwinds, **the EV market remains strong, with growth continuing** albeit at lower levels than in the early stage of adoption. In the next four years, passenger electric vehicle sales will grow at an average of 21% per year, building on the previously rapid initial growth that characterised the EV sector's infancy.

3. Batteries used in EVs will **displace 23 million barrels of oil per day (Mb/d) by 2040**, preventing 2.7 gigatons (Gt) of CO2 emissions the same year.

4. Global annual demand for cobalt from batteries will grow more than three-fold between 2020 and 2050, reaching 250kiltons by 2050. This will be driven by global commitments to achieve net-zero. Batteries will remain the key driver of growth, accounting for 60% of overall cobalt demand by 2050.

5. Cumulatively, **the overall battery industry will require at least 5.5 million tons of cobalt between 2023 and 2050** to power electric vehicles, consumer electronics and stationary storage – critical energy transition industries.

6. More cobalt will also be used in the consumer electronic segment, driven by batteries used in Artificial Intelligence (AI) devices, robotics and drones. Cumulatively, the consumer electronics industry will need at least 2.2 million tons of cobalt between 2023 and 2050.

7. Demand for cobalt in superalloys is expected to grow almost four-fold between 2020 and 2050. This is due to the recovery in commercial aviation post-Covid, but also the growing number of orders for defence aircraft, the development of next-generation air force equipment, as well as the growth in applications for space exploration and satellites.

8. Growth in demand for cobalt will require a corresponding expansion in supply. **At least $1.7 billion in new investment is required by 2050 to build the cobalt mines needed to meet global battery demand for net zero. It is therefore urgent that the needed capital is deployed today to build a reliable cobalt supply chain and prevent deficits in future.**

9. Recycling can help meet up to 18% of new global cobalt demand by 2035 across passenger EVs, commercial EVs, e-buses, two-/three-wheelers and stationary storage. However, this will require substantial investments today to ensure the industry is adequately prepared when current generation lithium-ion batteries reaches the end of their initial operating life of roughly six to 15 years.

10. If we are going to realise this challenging yet achievable goal, **it is essential that governments implement good policies that incentivize demand, competitively grow supply and prioritize recycling.** This will ensure that cobalt's potential is fully unlocked to support the energy transition.

2. COBALT MARKET OVERVIEW: GROWTH REMAIN RESILENT

Cobalt is a technology-enabling metal that will play a major role in developing the green energy transition. Besides being a critical component of many batteries, it is also used in electronic devices, airplanes, power plants, pigments and a range of other industrial applications. It also infinitely recyclable, strengthening its role in the transition.

Despite the economic slowdown in China and high interest rates in US and Europe, cobalt's growth has remained resilient. The superalloy, hard metal, pigment, catalyst, permanent magnet and hard facing market for cobalt collectively grew by 11% year-on-year. The biggest driver for this growth was the superalloy segment, which is mostly used by the aerospace and power industries.

Rising tensions between China and the US, as well as the war in Ukraine, have led to an uptick in defence spending. The slow recovery of China's economy as well as the lowering of interest rates in Europe and the US will provide support for cobalt growth over the rest of the decade.

Cobalt use in the consumer electronic segment has been sluggish for the last 12 months. The rising cost of living over the last two years has negatively impacted household spending in this segment. The rise of artificial intelligence will lead to a wave of new electronic devices, such as wearables. These devices will boost demand for cobalt used in making the batteries.

Demand from electric vehicles (EV) now represents the biggest end-use segment for cobalt.

The EV market remains strong, with growth continuing albeit at lower levels than the predictably rapid early-stage expansion of previous years. In 2023, electric vehicles accounted for 17.8% of all passenger vehicle sales globally and a record 61% in the Nordics. Several countries are also moving faster than the global average: in China, over 37% of all cars sold were electric, followed by Germany, France and the UK, which all surpassed 25%.

EV sales are set to rise from 13.9 million in 2023 to over 30 million in 2027 in BNEF's Economic Transition Scenario. In the next four years, electric car sales grow at an average of 21% per year, compared to the average of 61% between 2020 and 2023 that characterised the EV sector's infancy. The predominant battery used in electric vehicles today is the lithium-ion battery. At the end of 2023, there was 2.5 terawatt-hours per year (TWh/year) of commissioned lithium-ion battery manufacturing capacity globally, more than 20 times that online in 2015.

If all additional planned plants are built, total capacity would increase to 9.4TWh/year by the end of 2026. While capacity is heavily concentrated in China, new cell-manufacturing capacity in Europe, and increasingly in the US, is beginning to ramp up to support growing battery demand in those regions.

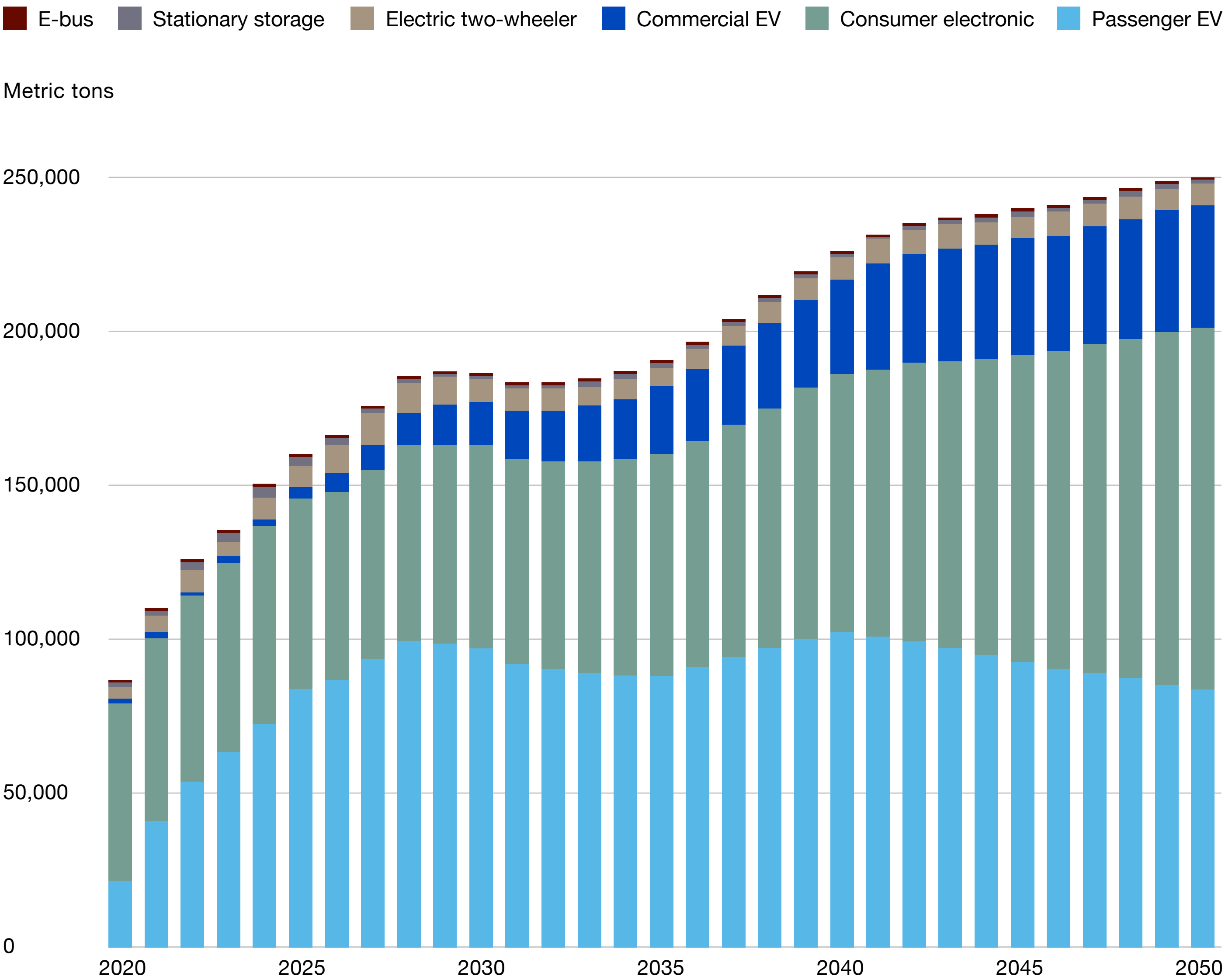
Lithium-ion batteries use metals such as cobalt in the cathode. The growth in demand for these batteries will lead to a corresponding growth in cobalt's end-use. The EV industry's consumption of cobalt rose more than four-fold to 85,000 metric tons by the end of 2024, from the modest level of 28,000 metric tons in 2020.

Prices of cobalt have fallen significantly from a peak of $81,000 per metric ton in April 2022 to $24,000 per metric ton in September 2024. This has affected production of the metal. With demand set to grow, persistently low prices could lead to a period of deficits in the future.

3. DEMAND: ALL KEY SECTORS TO DRIVE GROWTH

- **Global demand for cobalt from batteries will grow more than three-fold from a modest consumption of 85,000 metric tons in 2020 to 250,000 metric tons by 2050.**
- **This growth in annual demand will require a corresponding growth in supply.**
- **Cumulatively, the overall battery industry will require 5.5 million metric tons of cobalt by 2050 to power electric vehicles, consumer electronics and stationary storage.**

Figure 1: Global cobalt demand from batteries



Source: BloombergNEF

SCENARIOS AT BLOOMBERG NEF (BNEF)

BNEF's cobalt outlook combines near-term forecasts with a long-term scenario. From 2024 to 2027 it includes a bottom-up forecast for each vehicle, battery or metal. This takes into account factors like current and upcoming models available, policy and incentive frameworks, historical growth rates, consumer adoption patterns and other factors. From 2028 onward, the outlook splits into two long-term scenarios:

Economic Transition Scenario (ETS): This is the main scenario described in this report. It assumes no new policies or regulations are enacted that impact the market. It also does not assume any long-term climate targets are hit, or that any combustion vehicle phase-out targets that have been announced by countries, states, cities or companies are achieved. Instead, adoption is primarily driven by techno-economic trends and market forces. Unless otherwise stated, charts and analysis in this report refer to the ETS also referred to as the base case in some instances.

Net Zero Scenario (NZS): This scenario investigates what a potential route to net-zero emissions by 2050 might look like for road transport and metals consumption. This scenario looks primarily at economics as the deciding factor for which drivetrain technologies are implemented to hit the 2050 target. The Net Zero Scenario is one of a number of possible pathways that could meet this goal, and we do not present this as the most likely.

3.1. BATTERY DEMAND

- **Annual demand for cobalt from EVs will rise more than four-fold by 2035 to 115,000 metric tons, driven by some countries' ambitious targets to phase out internal combustion engines by 2035.**
- **Post-2035, a second phase of demand growth for cobalt will be driven by commercial EVs, which will favour the longer range provided by nickel-manganese-cobalt batteries.**

Figure 2: Global long-term passenger EV sales by market – Economic Transition Scenario

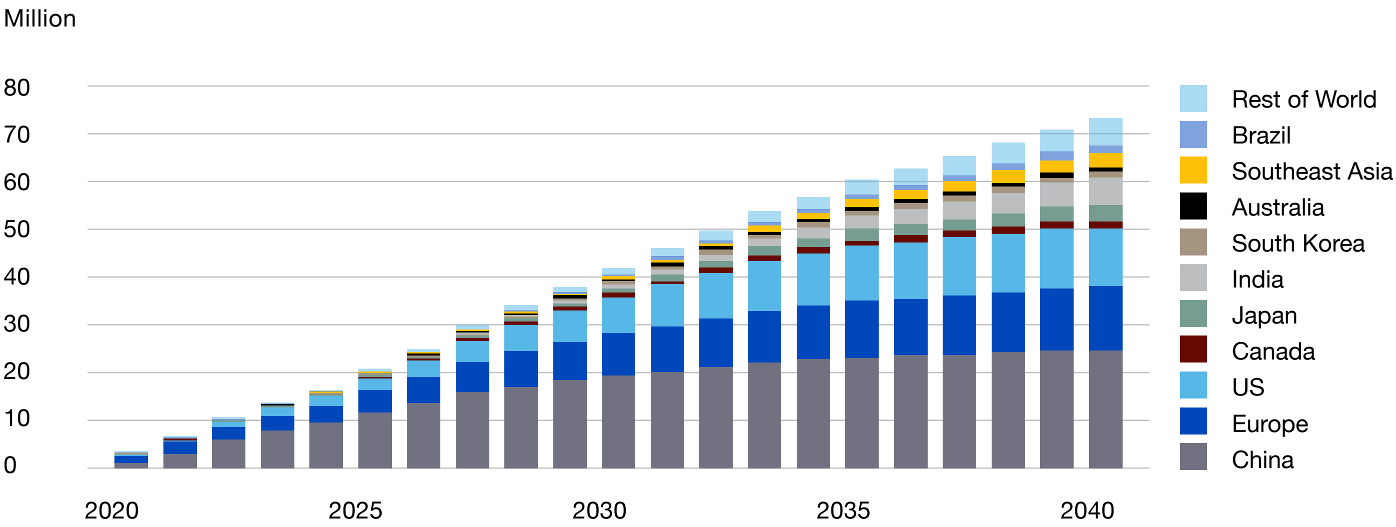
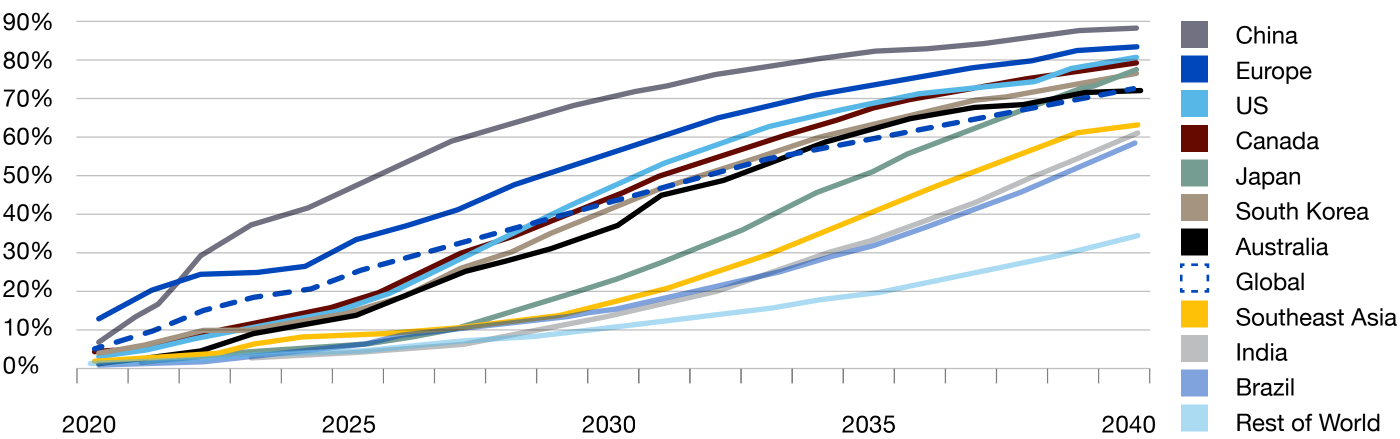


Figure 3: Global long-term EV share of new passenger-vehicle sales by market – Economic Transition Scenario



Source: BloombergNEF. Note: Europe includes the EU, the UK and European Free Trade Association (EFTA) countries. EV includes battery EVs and plug-in hybrid EVs

The EV share of global new passenger vehicle sales will jump to 33% in 2027, from 17.8% in 2023. Only China (60%) and Europe (41%) are above that global average by then, but some European car markets move even faster, with the Nordics at 90% and Germany, the UK, and France all well above 40%.

In the US, EV market jitters inflamed by the upcoming presidential election slowed adoption this year, and by 2027, 29% of cars sold in the country will be electric.

Still, the underlying technology for EVs continues to get better and cheaper, both for lithium-based battery chemistries such as LFP, and nickel-based chemistries containing cobalt.

Many new, lower-cost EV models are set to launch in the next few years. Some of the fastest growth rates are in emerging economies, with EV sales set to quintuple in Brazil by 2027 and triple in India. The fleet of electric cars grows fast, rising to over 132 million by 2027, from 41 million passenger EVs on the road at the end of 2023.

BNEF's economic analysis indicates that EVs will be the primary method of decarbonizing road transport. However, hybrids can also play a meaningful role. In Europe, the US, China, Japan and South Korea, we expect full-hybrid sales to surpass 15 million units annually by 2030, out of 95 million vehicles sold globally the same year.

After increasing rapidly this decade, EV sales growth slows from 2030 in China and from the mid-2030s in Europe and the US as both markets begin to saturate. Although public charging infrastructure is growing at pace globally, it still presents a barrier to electrifying the last 10% to 20% of the market in many countries.

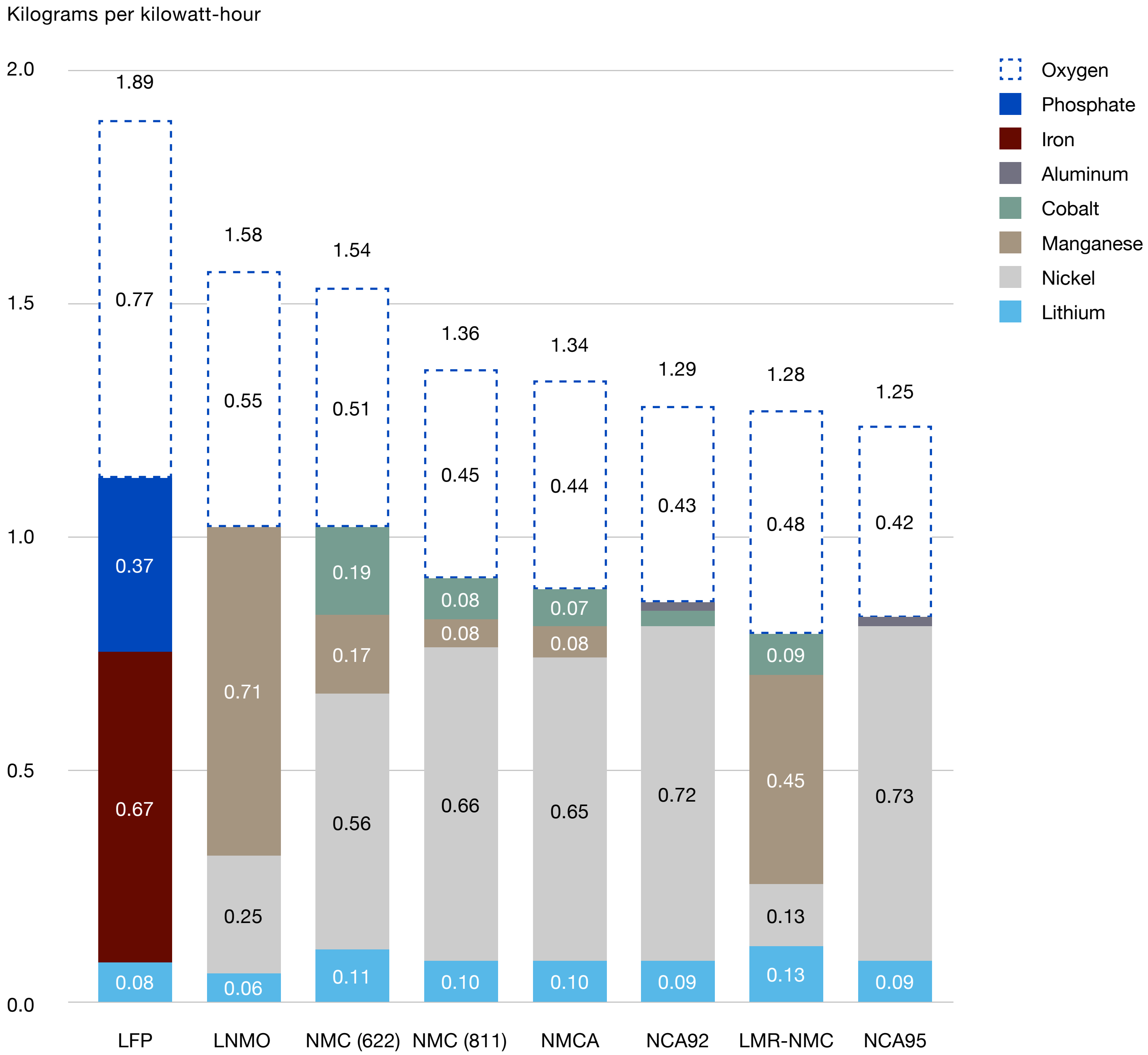
WHAT IS A LITHIUM-ION BATTERY?

Lithium-ion batteries were commercialized in 1991. Over the coming decades, they would become commonplace in consumer electronics ranging from mobile phones and laptops to power tools and eventually drones. The Tesla Roadster in 2008 was the first mass-produced electric vehicle to use lithium-ion cells.

The lithium-ion battery is made up of an anode and a cathode. Some cathode materials use cobalt. Multiple cathode chemistries remain in use, each with different characteristics. The cathode chemistries are named based on the specific materials used in each type. Lithium-iron-phosphate batteries, for example, are typically known as LFP. A nickel-manganese-cobalt oxide (NMC) battery is further identified by the proportion of those materials to each other. An NMC (811) battery has 8 parts nickel to 1 part of manganese and cobalt.

One of the reasons why the market has not yet converged around a single cathode chemistry is that each involves tradeoffs. Current iterations of an NMC (811) battery for instance have very high energy densities but have a short cycle life. An LFP battery, by contrast, tends to have a longer cycle life but not to be as energy dense.

Figure 4: Metal content of selected lithium-ion battery cathode materials



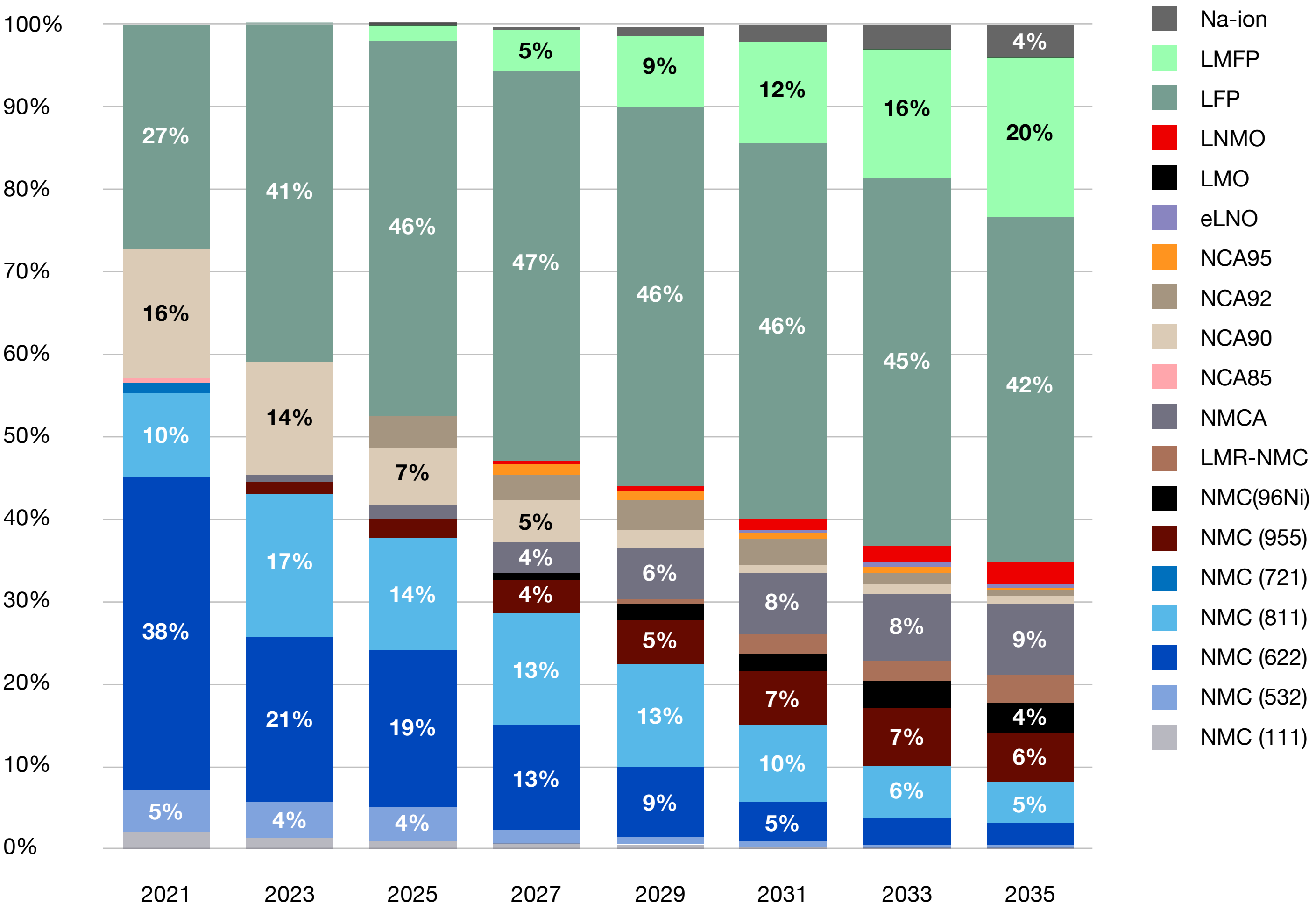
Source: BloombergNEF

Note: LFP refers to lithium iron phosphate; LNMO is lithium nickel manganese oxide; NMC is nickel manganese cobalt oxide; NMCA is nickel manganese cobalt aluminum oxide; NCA is nickel cobalt aluminum oxide; LMR is lithium- and manganese-rich

Annual lithium-ion battery demand grows rapidly in BNEF's Economic Transition Scenario (ETS) to almost quadruple today's levels, approaching 3.6 terawatt-hours (TWh) across road transport and stationary storage by the end of the decade.

The starting point for BNEF's cathode chemistry outlook is the current breakdown of chemistries used in different EVs and the number of vehicles sold. We combine this with our knowledge of new and existing chemistries, future vehicle release dates and other company announcements to estimate how the chemistry mix could change between now and 2035 (Figure 5).

Figure 5: Evolution of cathode chemistry mix across all passenger electric vehicle segments



Source: BloombergNEF

Note: Na-ion refers to sodium ion; LMFP is lithium manganese iron phosphate; LFP is lithium iron phosphate; LNMO is lithium nickel manganese oxide; LMO is lithium manganese oxide; LNO is lithium nickel oxide; NCA is nickel cobalt aluminum oxide; NMCA is nickel manganese cobalt aluminum oxide; LMR is lithium- and manganese-rich; NMC is nickel manganese cobalt oxide.

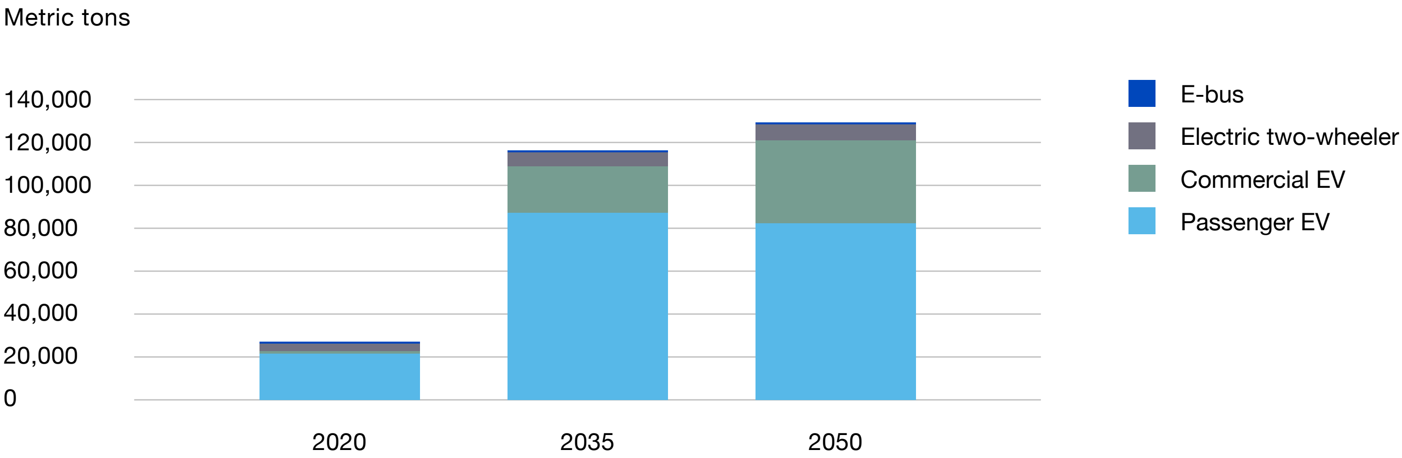
The annual demand for cobalt from electric vehicles will rise more than four-fold by 2035, to 115,000 metric tons from the 2020 level of c.26,000 metric tons. The growth is driven by the ambitious targets set by the European Union, Singapore, Canada, Chile, the UK and other countries to phase out internal combustion engines by 2035.

Automakers are currently investing in the commercial vehicle segment to improve its performance and lower costs. Commercial vehicles, which include heavy duty and long-haul trucks, require batteries that can travel long distances on a single charge. The nickel-manganese-cobalt chemistry is best suited for this.

The penetration of electric commercial vehicles will lead to a corresponding rise in cobalt used in their batteries, increasing from 22,000 metric tons in 2035 to 39,000 metric tons by 2050.

Cumulatively, the EV industry will need at least 3.3 million metric tons of cobalt between 2023 and 2050 to develop batteries under BNEF's base case scenario.

Figure 6: Annual cobalt demand from electric vehicles

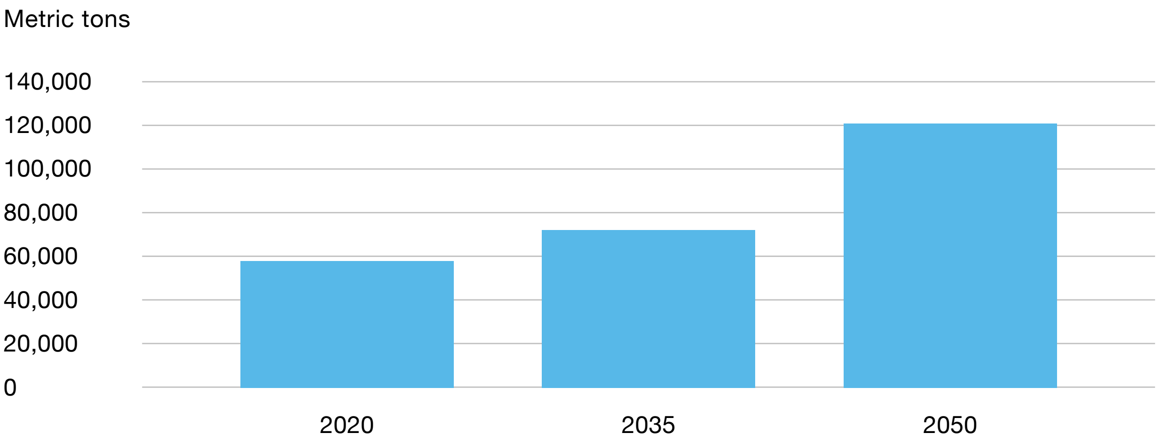


Source: BloombergNEF

CONSUMER ELECTRONICS

- **Annual consumption of cobalt in consumer electronics will rise steadily to 72,000 metric tons in 2035 from the 2020 level of 59,000 metric tons, driven by growth in artificial intelligence, robotics, drones and smart devices and the cobalt used in the lithium-ion batteries that power them.**
- **From 2035 to 2050, cobalt demand will rise yet faster, underpinned by the increasing wave of growth in these emerging technologies.**
- **Cumulatively, the demand from consumer electronics between 2023 and 2050 is 2.2 million metric tons under BNEF's economic transition scenario.**

Figure 7: Annual cobalt demand from consumer electronics

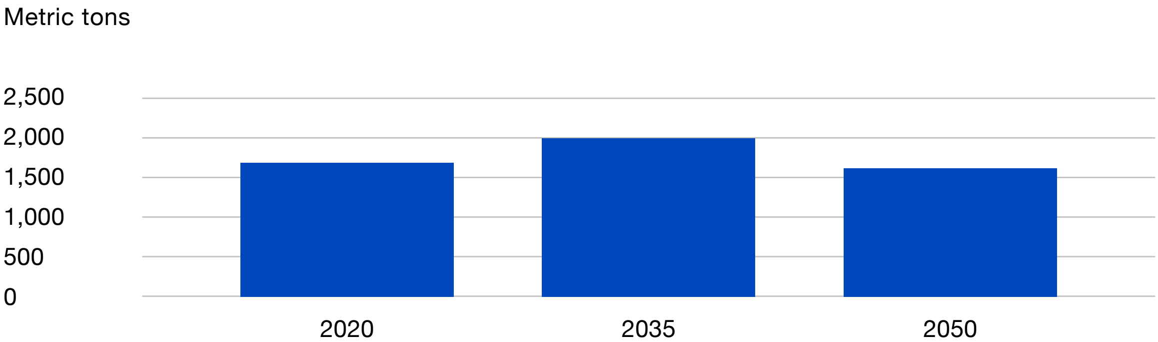


Source: BloombergNEF

STATIONARY STORAGE

- **Despite a decline in the market share of nickel-based battery chemistries such as nickel manganese cobalt oxide (NMC), the stationary storage industry will still require cobalt.**
- **Annual global cobalt demand from stationary storage has risen from 1,700 metric tons in 2020, peaks this year at 3,500 metric tons before dropping to an annual average of 1,400 metric tons until 2050.**
- **Cumulatively, the stationary storage industry will consume 39,000 metric tons of cobalt between 2023 and 2050 under BNEF's base case scenario.**

Figure 8: Annual cobalt demand from stationary storage



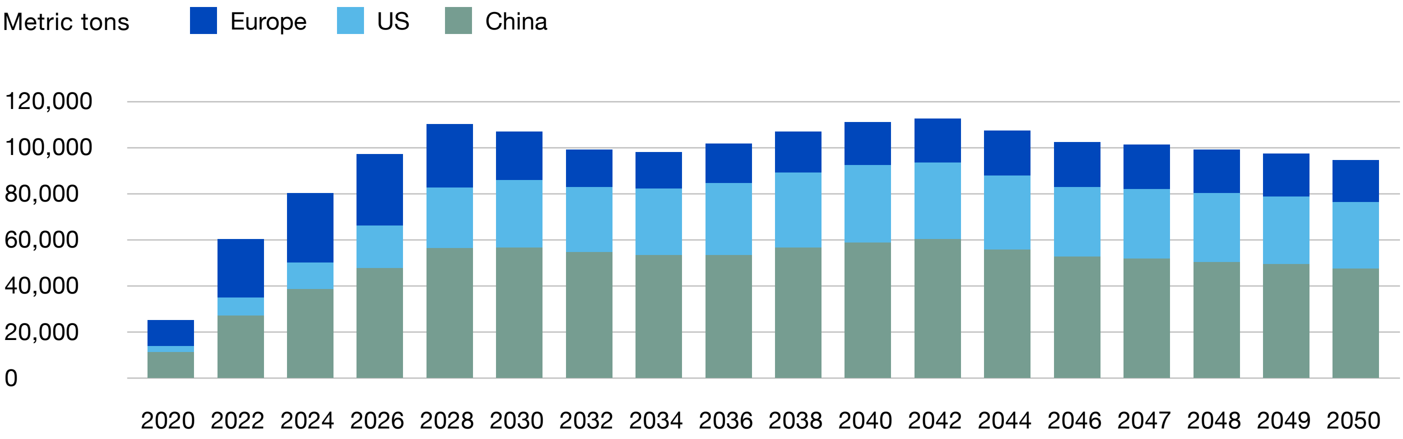
Source: BloombergNEF

Annual cobalt demand from stationary storage has risen from 1,700 metric tons in 2020, peaks this year at 3,500 before dropping to an average of 1,400 metric tons until 2050.

CHINA

- **Within China's fast-growing EV market, cobalt demand will increase four-fold by 2050, reaching 47,000 metric tons from the 2020 level of 11,000 metric tons.**
- **Market share in China's passenger EV mix for nickel manganese cobalt oxide (NMC) battery chemistry will half to 30% by 2035, primarily driven by the penetration of other technologies such as LMFP and sodium-ion.**
- **There will, however, still be significant overall growth by 2035 in absolute terms of NMC chemistry to 311GWh from the 2020 level of 32GWh.**

Figure 9: Regional breakdown of cobalt demand from electric vehicles



Source: BloombergNEF

China's passenger EV sales will reach 9.9 million units in 2024, up 21% from 2023. Sales have been driven by a new wave of demand-boosting price cuts by a number of automakers including BYD. After 2024, passenger EV sales in China will continue to grow at an average of 18% annually until 2027.

China lacks a strong regulatory push as both the fuel-economy goal and New Energy Vehicle (NEV) credit scheme targets for 2025 were already met or exceeded in 2022, and the longer-term objective of NEVs making up 40% of new car sales by 2030 will most likely be met this year.

China's EV market is now shaped primarily by consumer demand and sales will be slowed by market saturation and a tougher economic outlook.

US

- **Cobalt demand in the US electric vehicle market will grow by a factor of almost 10 by 2050, rising from the 2020 level of 3,000 metric tons to 29,000 tons.**
- **The market share of the NMC battery chemistry in passenger electric vehicles sold in the US will reach 50% in 2035, challenged by the adoption of cheaper chemistries providing better margins for automakers taking advantage of the Inflation Reduction Act.**
- **Despite this decline in market share, the absolute growth in NMC use will increase strongly from 25GWh in 2020 to 398GWh by 2035.**

Following a sluggish 2024, some moderate optimism in the EV market arrives in 2025 as a few new EV models are launched, and as the Inflation Reduction Act increases manufacturing capacity of automakers like Hyundai, BMW or Toyota. This is followed by more affordable, mass market EVs arriving in 2026 from companies like Ford.

Passenger EV sales in the US have grown 20% in 2024 compared to 2023, to just under 1.8 million units. This marks a slowdown from 2023 growth rate (49%) as some of the major automakers, like Ford and General Motors, continue to struggle with production and sales ramp up, and as Tesla failed to refresh its model line-up in a meaningful way.

Remaining key automakers, like Hyundai, Kia or Volvo, continue to increase their EV sales in 2024, albeit from a low base. EVs grow to make up nearly 29% of passenger vehicle sales by 2027, up from 10% in 2023. As a result, the US accounts for 15% of global passenger EV sales in 2027, up from 11% in 2023.

EUROPE (EU + EFTA + UK)

- **Cobalt demand will increase to c.18,000 metric tons by 2050 from the 2020 figure of c.11,000 metric tons, driven by absolute battery demand growing strongly from 55GWh to 213GWh over the same period.**
- **The market share of the NMC battery chemistry in passenger electric vehicles will drop from c.95% in 2020 to c.40% in 2035.**
- **This slower demand growth compared to China and the US is due to the major auto makers in Europe committing to variations of NMC 955, which uses less cobalt. If building the capacity for these newer chemistries presents challenges, automakers in Europe might revert to the NMC 622 or NMC 532, which use more cobalt.**

EV sales in Europe come in at just under 3.5 million in 2024, some 10% higher than in 2023. The underwhelming growth is mainly down to weaker pressure from fuel-economy targets this year. The European Union's CO2 targets will not become more stringent until 2025, keeping EV market growth in the region muted until then.

The lower pace of growth reflects the increasing uncertainty over EV sales in Germany, where the removal of EV purchase incentives combined with tough economic conditions risk putting off EV buyers. There remains the chance, however, that countries such as France or the UK will pick up some of the potential lost demand in Germany.

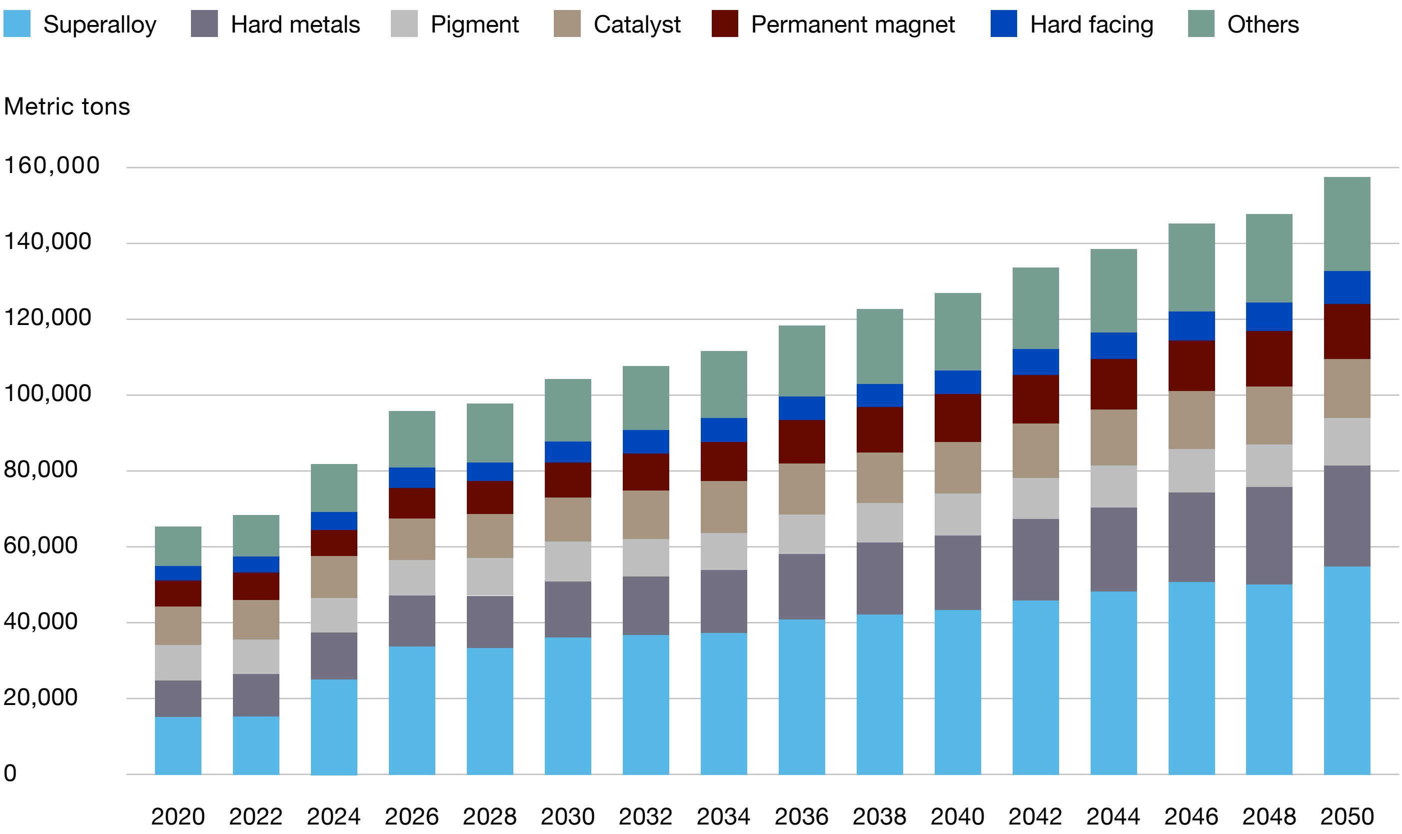
The 2024 picture in Europe also has some positive signs. Several potentially very popular, low-cost EVs, like the Citroen E-C3 (priced at €23,300) and the Renault 5 E-TECH (priced at around €25,000) are set to be released this year – both addressing the popular small vehicle segment.

In the UK, 2024 is the first year of the Zero Emission Vehicle (ZEV) mandate, with 22% of car sales in the country mandated to be zero-emission this year. By 2027, over 41% of new UK passenger vehicle sales will be electric.

3.2. INDUSTRIAL DEMAND

- **Demand for cobalt from industrial end-use will more than double from 65,000 metric tons in 2020 to 157,000 metric tons by 2050, primarily driven by strong growth in superalloys and hard metals.**

Figure 10: Total cobalt demand from industrial demand

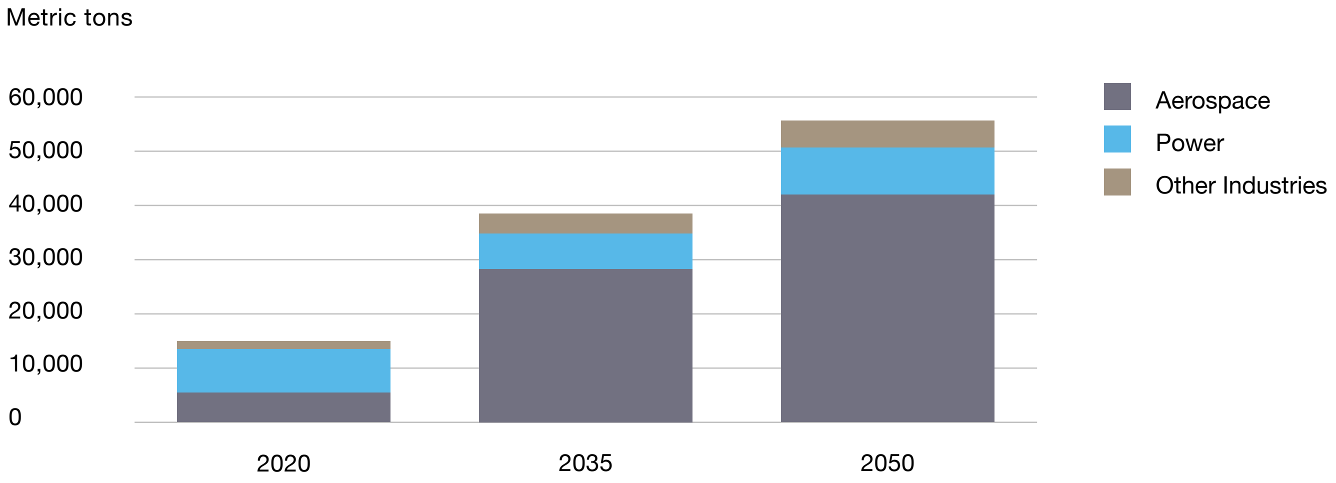


Source: BloombergNEF

SUPERALLOYS

- **Cobalt demand from superalloys will multiply nearly four-fold by 2050, rising to 55,000 metric tons from the 2020 level of 15,000 metric tons.**
- **This demand for cobalt will be primarily driven by the aerospace sector, underpinned by strong growth in both commercial and defence aviation, as well as space applications.**

Figure 11: Cobalt demand from superalloys



Source: BloombergNEF, Cobalt Institute

Superalloys are alloys that are able to function efficiently under high temperature (above 600°C) and pressure (above 35 MPa). Superalloys are commonly used in the aerospace industry, in gas turbines for power generation, and the oil and gas industry.

The three main types of superalloys are iron-based, nickel-based and cobalt-based. Cobalt content for iron-based and nickel-based superalloys can range between 10-20% of the total metal composition. The cobalt content for cobalt-based superalloys can be up to 80% of the total metal composition. Although nickel alloys make up about half of the superalloys market, cobalt alloys are preferred in some instances due to their higher melting point. Cobalt alloys also offer better corrosion resistance than iron and nickel-based alloys.

The innovation cycle for superalloys typically spans 20 years, thus we do not expect the cobalt content of various alloys to change significantly over the next two decades.

Table 1: Selected alloys and their key metals composition

Type	Alloy	v	Nickel (%)	Iron (%)	Chromium (%)
Iron-based	Haynes 556	20	21	32.2	22
	Ally N-155	20	20	29	21
Nickel-based	Haynes 214	0	76.5	3	16
	Haynes 230	5	55	3	22
Cobalt-based	Haynes 188	22	–	3	–
	Stellite B	30	–	1	–

Source: BloombergNEF, Singh (2016) [1]

[1] Singh 2016, Superalloys Report, Technical Report

The commercial aviation industry witnessed a steep drop in orders in 2020 due to the impact of Covid-19 on air travel. It has since recovered with higher growth projections expected over the next two decades.

Defence aircraft orders are expected to grow as well. The war in Ukraine as well as other regional conflicts and rising tension between the US and China are driving investments in next-generation defence aircraft. This will boost the demand for cobalt.

Additionally, growth in applications such as rockets used for space exploration and satellite launches will expand demand for superalloys mid-decade.

To forecast the cobalt content used in superalloys for power plans, BloombergNEF used data from its New Energy Outlook (NEO) 2024. According to NEO 2024, total new-build power plants ranging from gas to nuclear will grow from about 430GW in 2020 to about 856GW in 2050 under BNEF's base case scenario. Most of these technologies contain superalloys.

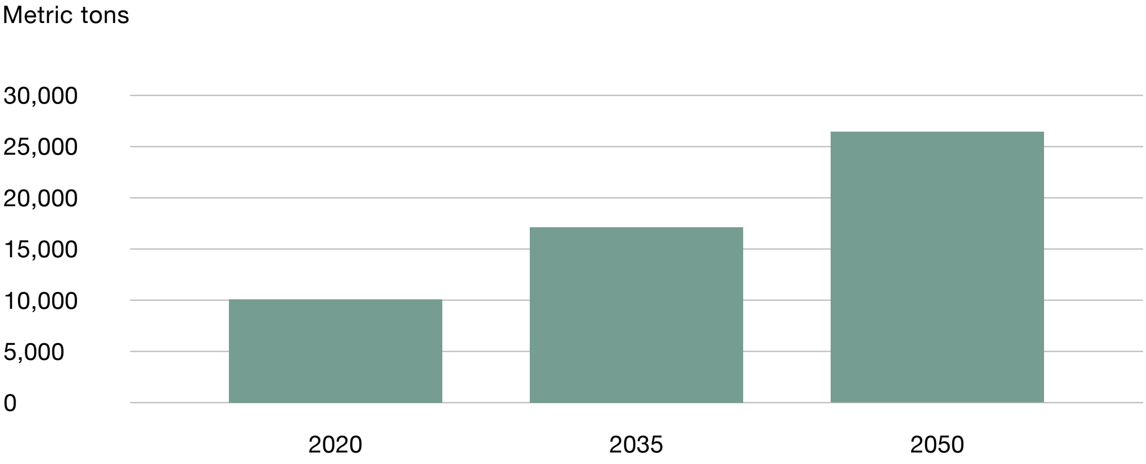
BNEF developed the average intensity for these technologies to estimate the cobalt consumed by the power industry. The model accounts for material efficiency over time as a result of technology improvement and learning rate.

To approximate for smaller superalloys demand from other end-use application such as heat exchangers, we added an extra 10% of each year's annual demand from the aerospace and power industries, which is roughly their current proportion of the global market.

HARD METAL

- **Cobalt demand in hard metals will more than double to 26,000 metric tons by 2050 from its 2020 level of 10,000 metric tons, driven by hard metals use in the mining, energy, automotive and aerospace industries.**

Figure 12: Annual cobalt demand from hard metals



Source: BloombergNEF, Massachusetts Institute of Technology

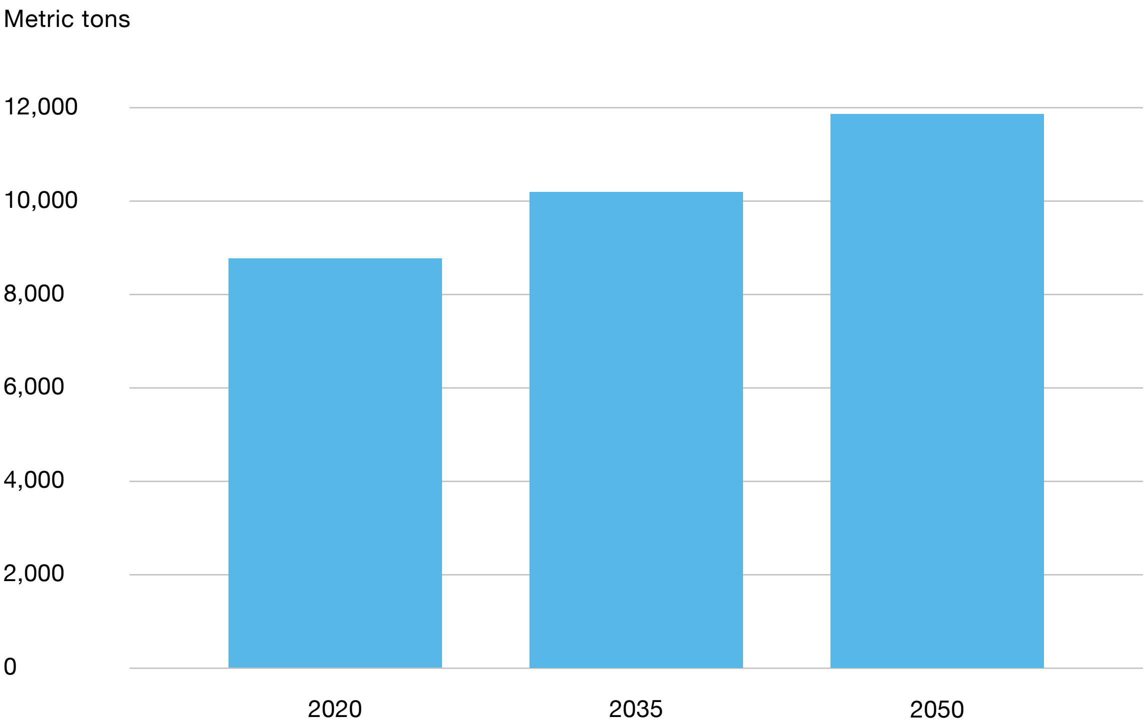
Hard metals are used in diamond drilling equipment, cutting tools, and high-speed steel and metal rollers. An example is tungsten carbides, in which cobalt is used as a binder to increase resistance to wear and raise hardness. Various hard metals are used in mining, energy, automotive and aerospace industries.

To estimate cobalt demand in hard metals we used an average growth rate of about 3%. This is in line with the underlying industries that hard metals depend on. The energy transition, population growth and new infrastructure build will drive the need for industrial tools.

CERAMICS AND PIGMENT

- **Demand for cobalt in the ceramics and pigment industry will grow steadily to 12,000 metric tons by 2050 from its 2020 level of c.9,000 metric tons.**

Figure 13: Annual cobalt demand from ceramics and pigments



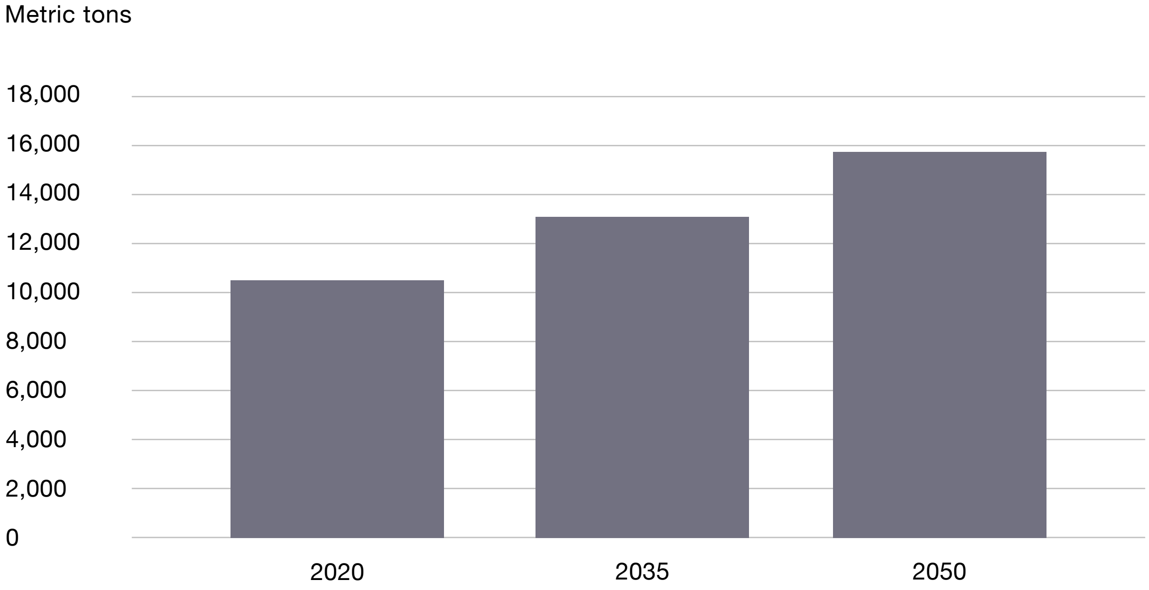
Source: BloombergNEF

In addition to its industrial applications, cobalt also adds colour to life. It is used in paints, porcelain, ceramics and glass for blue pigmentation. Over the last decade, demand for cobalt used by the ceramics and pigment industry has grown at an average of around 1% per year. We do not expect this to change up to 2030. Thus, we project the ceramics and pigment industry use of cobalt to grow from about 9,000 metric tons in 2020 to 12,000 metric tons by 2050.

CATALYST

- **Demand for cobalt as a catalyst will rise steadily to 15,700 metric tons by 2050 from its 2020 level of 10,500 metric tons, driven by cobalt's use as an oxidizing agent for various processes in the chemicals and petroleum industries.**

Figure 14: Annual cobalt demand as a catalyst



Source: BloombergNEF

Cobalt is also used as an oxidizing agent for various chemical processes. It can be converted into various chemical compounds with wide range of applications in the hydroformylation of plastics, catalyzation of gas-to-liquid production processes and reduction of sulfur content in petroleum.

To estimate cobalt demand from the chemical industry, we first determined the growth trajectory of the chemical and petroleum industries. In spite of countries and companies backing commitments to reduce plastic use, BNEF projects global production of plastic materials such as low-density and high-density polyethene will grow by 28% and 25% respectively by 2030.

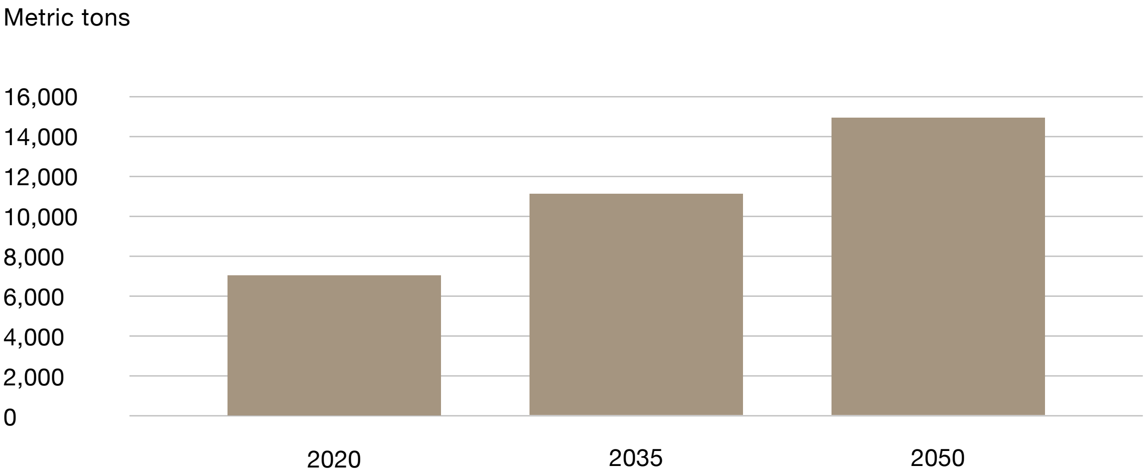
After 2030, countries and companies are finding sustainable alternatives to plastic products that may slow this growth rate. Polypropylene is a linear polymer that is tough and fatigue-resistant and mostly used in rigid applications for both single-use items such as yogurt cups and long-term applications such as kitchen utensils. Its production will also grow by 32% by 2030.

Platinum group metals (PGMs) are used as catalysts in proton exchange membrane electrolyzers, which produce hydrogen. Platinum and iridium are currently the most used PGMs here, but companies are looking to reduce their PGM loading in electrolyzers by introducing cobalt as a catalyst. We included this shift in the modeling but the impact on cobalt demand is marginal over the long term.

PERMANENT MAGNETS

- **Demand for cobalt in permanent magnets will more than double to 14,800 metric tons by 2050 from its 2020 level of 6,900 metric tons, driven by growth in the use of permanent magnets in electric and hybrid vehicles, wind turbines and consumer electronics.**

Figure 15: Annual cobalt demand from permanent magnets



Source: BloombergNEF, Arnold Magnetic Technologies

Permanent magnets increase efficiencies in direct-drive electrical motors and generators used in electric and hybrid vehicles and wind turbines. They are also used in consumer electronics such as mobile phones, laptops and loudspeakers. Neodymium-iron-boron (NdFeBo) and Samarium-cobalt (SmCo) magnets are the most common permanent magnets. The iron cobalt (FeCo) magnet also has industrial use cases as well.

SmCO magnets, which contain significant amounts of cobalt, are preferred in some cases over NdFeBo magnets due to their ability to tolerate a wider temperature range and higher corrosion. NdFeBo magnets, which do not contain a significant amount of cobalt, provide a higher magnetic strength.

Another cobalt-containing permanent magnet is the aluminum-nickel-cobalt (Alnico) magnet. BNEF assumed an average cobalt content of 40% for various grades of Alnico magnets and 70% for SmCo.

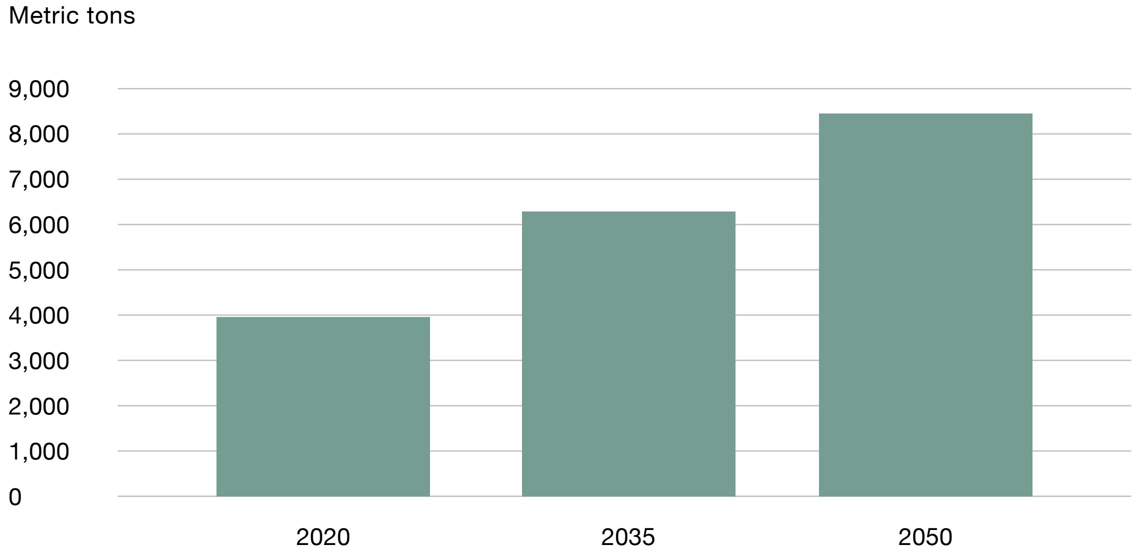
To forecast demand for cobalt used in SmCo and Alnico magnets, we applied the growth rate of the industry over the last decade projected by Arnold Magnetic Technologies, and adjusted it to account for the projected growth in defense and other industrial use-cases.

Based on these growth rates, demand for cobalt from Alnico magnets will grow from 2,700 metric tons in 2020 to 6,000 metric tons by 2050. Demand from SmCo magnets will grow from 2,400 metric tons in 2020 to 5,000 metric tons by 2050. Other permanent magnets are accounted for by assuming a 10% additional consumption for each year.

HARD FACING

- **Demand for cobalt in the hard facing sector will more than double to 8,500 metric tons by 2050 from its 2020 level of 4,000 metric tons.**

Figure 16: Annual cobalt demand from hard facing



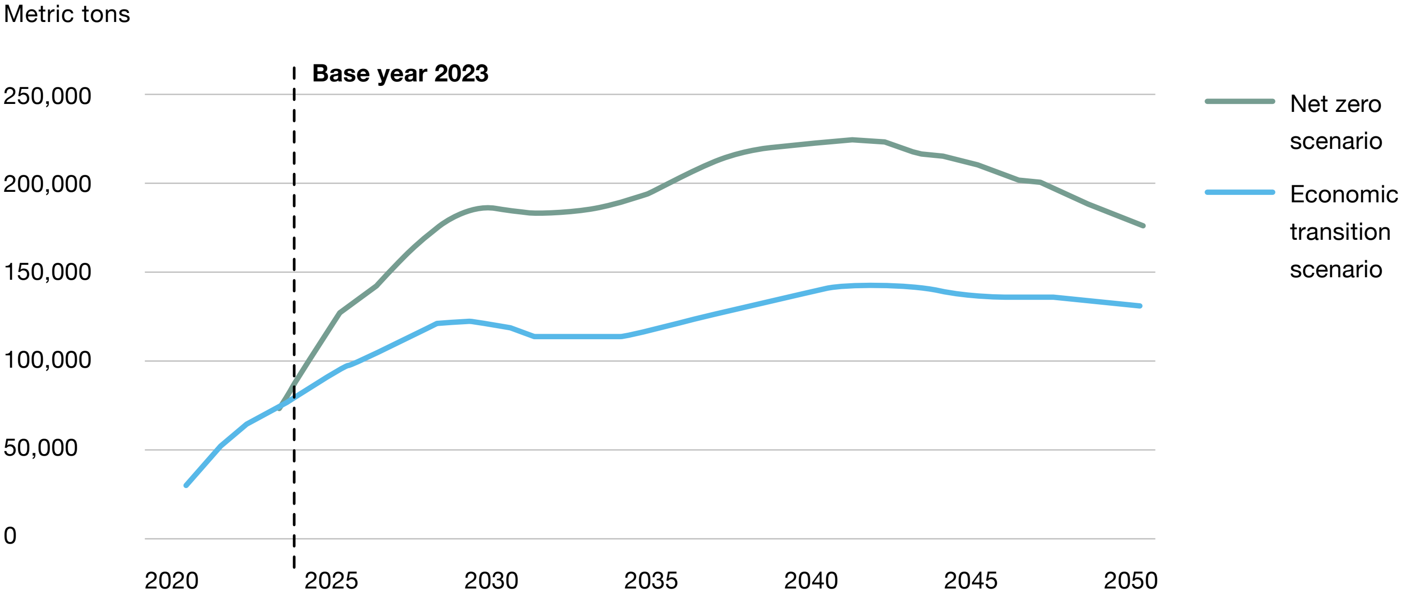
Source: BloombergNEF, Cobalt Institute

Hard facing materials will play a key role in the growing consumption of cobalt. These are materials that are welded onto surfaces to increase their resistance and resilience. The rest of this decade will record rising interest in infrastructure from emerging economies like India and nations in Africa. This will lead to a relatively higher growth in the consumption of hard facing materials. BNEF assumed a 3% growth rate this decade. This is then reduced to 2% until 2050 in line with the macro-economic trends of the industries that underpin hard facing materials.

3.3. NET ZERO SCENARIO FOR BATTERIES AND COBALT

- **Accelerating the energy transition toward net zero will significantly reduce the amount of CO2 being emitted into the atmosphere.**
- **Reaching these 2050 net-zero targets will require the deployment of batteries at a significantly faster rate, meaning more cobalt used in electric vehicle and stationary storage batteries.**
- **The industry will need c.60% more cobalt than in the Economic Transition Scenario, equating to between c.130,000 and 180,000 metric tons of cobalt globally by 2050 for EV and storage.**

Figure 17: Cobalt consumption for electric vehicles and stationary storage, ETS and NZS



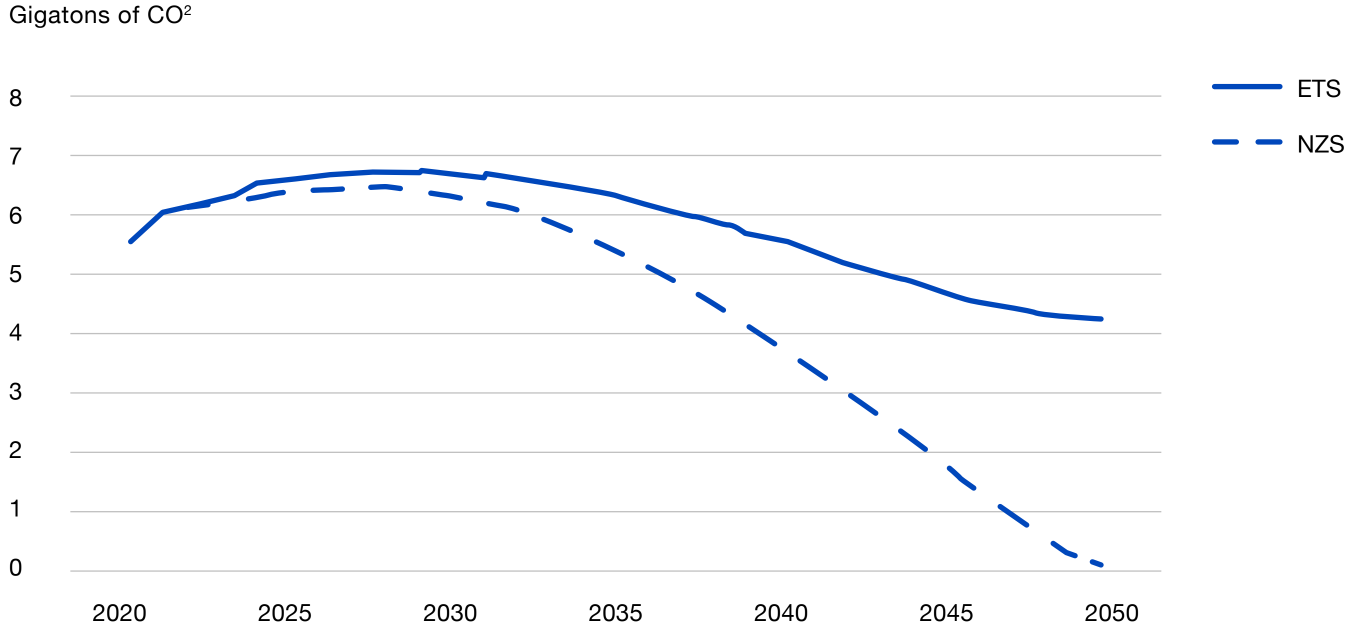
Source: BloombergNEF

Note: ETS is Economic Transition Scenario and NZS is Net Zero Scenario.

Automaker targets give a sense of the level of commitment to the zero-emission vehicle transition. Long-term pledges take many shapes and forms, but broadly fall into three categories: automakers committing to end new investment in internal combustion vehicles, those committing to phasing out ICE sales, and those committing to long-term net-zero emissions targets.

In BNEF's Net Zero Scenario (NZS), the number of zero-emission vehicles on the road grows much faster than in the Economic Transition Scenario (ETS). While in the ETS the passenger zero-emission fleet reaches 11% of the total fleet in 2030, it climbs to 15% in the NZS – a difference of around 44 million vehicles. Under the NZS, tailpipe emissions peak in 2027, one year earlier than in the ETS, and continue to decline steeply in the 2030s as more ICE vehicles are retired from the fleet.

Figure 18: CO2 tailpipe emissions from road transport – Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF
Note: Liquid-fuel emissions include passenger vehicles, commercial vehicles and two-/three-wheelers.
'ETS' is the Economic Transition Scenario, 'NZS' is the Net Zero Scenario.

While the difference in tailpipe emissions between the two scenarios is initially minimal, it expands quickly. By 2036, road transport tailpipe emissions are lower by 1GtCO2 in the NZS compared to the ETS, with a drop of more than 4GtCO2 in 2050.

4. COBALT MARKET 2050: INVESTMENT AND POLICIES NEEDED TO UNLOCK COBALT'S POTENTIAL

4.1. INFRASTRUCTURE INVESTMENT

- **Investment of over $1.7 billion is required by 2050 to build the cobalt mines needed to meet global battery demand for net zero.**

Cobalt will play an essential role in the deployment of batteries needed to reach net zero. At the moment, there are not enough cobalt mines to meet growing demand under BNEF's Net Zero Scenario. The industry will require $1.7 billion between now and 2050 to ensure sufficient cobalt.

This investment does not account for projects already announced by companies between now and 2035. As cobalt is mostly a by-product of copper and nickel, adding the capital cost of developing mines for these primary products will significantly increase this investment figure.

The average capacity for a cobalt mine today is approximate 5,000 metric tons. To meet demand for net zero, the industry will need an additional 30 average-sized mines operating at full capacity between now and 2050. Building these new mines could take up to 10 years in some jurisdictions. There is, therefore, an urgent need to deploy the needed capital today to prevent deficits in future.

4.2. POLICY

- **Good policies that incentivize demand, competitively grow supply and prioritize recycling will ensure cobalt can play its full role in delivering the energy transition.**

Battery supply chains are becoming central to major industrial policies across Europe and the US, and governments can play a critical role in onshoring them through support such as tax credits for cell production or EVs and lowering costs for interested buyers. These policies highlight that localization of the supply chain is not only tied to reducing the risk of relying on certain countries, but also taking advantage of the economic opportunities associated with the industry.

China: Chinese battery manufacturing owes its rise to support from local institutions and the national government. Access to cheaper labor, power and capital, in combination with a large domestic market, has sharpened local manufacturers' competitive edge. Early on, these advantages were significant, but building on them required subsidies. Before 2010, incentives provided to companies in the battery value chain ran as high as 75% of total costs. The sector was far smaller than it is today, but the sums involved were likely in the tens of billions of dollars. While the low cost of labour is not China's main competitive edge today, the country is seeing the benefits of decades worth of support in the battery industry. Policies delivered as recently as earlier in 2024 have been aimed at factory equipment replacement, regulating over-investment in capacity expansion to assess factory utilization, and reducing reliance on an export-only strategy.

US and Canada: In the US, the Inflation Reduction Act was signed into law by President Joe Biden on August 16, 2022, and represents the largest effort yet to strengthen the battery supply chain in the country. It introduced a variety of credits to support production, from raw materials to battery cells, modules, EVs and energy storage. Two of the key credits for batteries include production tax credits for cells and modules at $35/kWh and $10/kWh, respectively, and a $7,500 credit for EVs.

These credits will put downward pressure on prices for batteries manufactured in the US. Meanwhile, Canada's 2023 budget also offered support to the battery industry and the region is already attracting investment related to battery metals, components and manufacturing.

The annual demand for cobalt used in lithium-ion batteries for electric vehicles sold in the US will grow almost two-fold by 2035 and double by 2050. The US currently relies on Europe and China for its cobalt precursor materials, but Jervois and Electra Battery Materials are developing projects to help meet the US domestic demand. Without this new capacity coming online, US dependence on other countries for cobalt used in electric vehicles will only increase.

Europe: Following the passage of the Inflation Reduction Act in the US, the EU responded with its own Net Zero Industry Act. The proposed legislation includes the objective of having local manufacturers establish 550GWh of battery manufacturing capacity by 2030. Meeting this target seems easy, as cumulative announced battery manufacturing capacity exceeds it. However, these capacity numbers should be treated with caution: the Net Zero Industry Act provides little in the way of incentives to ensure this capacity gets built.

The European Union (EU) launched its Critical Minerals Act (CRMA) in 2023 to highlight the urgent need to strengthen and secure the EU's raw materials supply chain. The CRMA proposes a set of minimum targets for the EU's extraction, processing and recycling capacities to boost the share of its domestic supply. The non-legally binding nature of the targets, together with the lack of direct funding, means the bloc will struggle to attract new investments.

The EU will forge new partnerships with resource-rich countries to diversify its supply chain. But fierce competition for resources in US free-trade partners like Chile, which would enable electric vehicles to qualify for EV tax credits of up to $3,750 (half of the total available) under the US Inflation Reduction Act, will act as headwinds for the EU.

Obligatory reporting and stress-testing measures will be introduced under the Critical Raw Materials Act. If implemented well, these measures could be a game-changer that allow the bloc to effectively monitor and mitigate supply risk and track its progress against its targets.

Table 2: The EU's targets for domestic supply of strategic raw materials

Stage	Target supply as a percentage of EU's annual consumption
Extraction	10%
Processing	40%
Recycling	25%

Source: BloombergNEF, European Commission
Note: In the context of the regulation, 'processing' refers to all midstream stages of the value chain, excluding recycling.

Battery recycling policies are crucial for creating a sustainable battery and EV industry. Governments need to lay out regulatory frameworks specifically for batteries used in EVs and stationary storage, distinct from those for consumer electronics. By establishing collection networks, requirements for recovery rates and individual cell traceability, and principles of second-life battery management, these policies can build a robust system overseeing the full life cycle of EV batteries.

To date, China remains ahead of the EU and US when it comes to establishing battery recycling policy, although the EU and US have seen some progress over the last few years (Table 3).

Table 3: BNEF take on regional policies' effectiveness on electric vehicle battery recycling as of January 2024

		EU 2023 Agreement	China - National Guidance for NEV Battery Recycling	US
Recovery rate requirements	Cobalt	90%	98%	N.A.
	Starting date	2027	2018	N.A.
Traceability	Labeling	Required from 2026	Required	N.A.
	Reporting	Required from 2026	Required	N.A.
Collection network	Rate	51%	100%	N.A.
	Starting date	2028	2018	N.A.
Second-life batteries		Considered as new products	Repurposers are responsible for labeling, collecting and recycling the second-life batteries	N.A.
Extended producer responsibility		Manufacturers, importers and distributors	Automakers and battery manufacturers	N.A.
Government tax incentives		N.A.	N.A.	**10% of production costs for critical minerals and electrode active materials, and indirectly through EV credit requirements**

Source: BloombergNEF

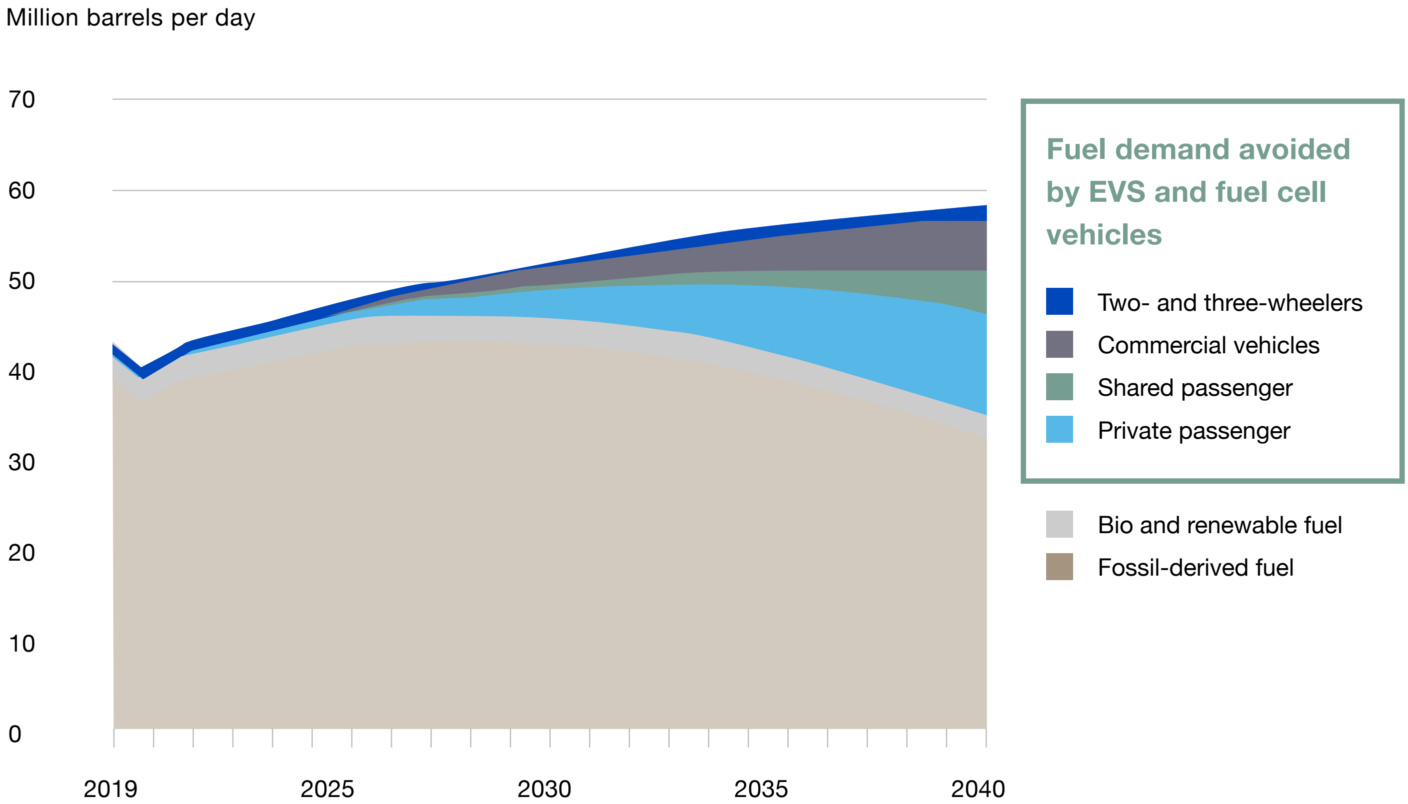
4.3. EMISSIONS

- **Batteries used in electric vehicles (EV) will displace 23 million barrels of oil per day (Mb/d) by 2040, preventing 2.7 gigatons (Gt) of CO2 emissions the same year.**

EVs of all types are already displacing nearly 1.8 Mb/d of oil. That is set to double by 2027, and triple by 2029, compared to last year's volumes. The pivot toward low-emission miles causes oil demand from road transport to peak by 2027 in our Economic Transition Scenario, some 2.5 million b/d higher than in 2023. Without the growth of EVs and fuel cell vehicles, road fuel demand would rise until 2040.

The rapid uptake of passenger EVs in markets like China, Europe and the US propel the jump in avoided oil consumption over the coming years as disruption to the status quo spreads beyond the bus, and two- and three- wheeler segments. In the EU ETS, oil demand from road transport declines by over 21% by 2040 compared to 2023 levels. Overall, 23 million barrels of oil will be displaced by 2040 as a result of electric vehicle penetration, according to BNEF's Economic Transition Scenario. This leads to the prevention of 2.7 gigatons of CO2 going into the atmosphere from tailpipe emissions.

Figure 19: Road demand and fuel displaced by electric and fuel-cell vehicles



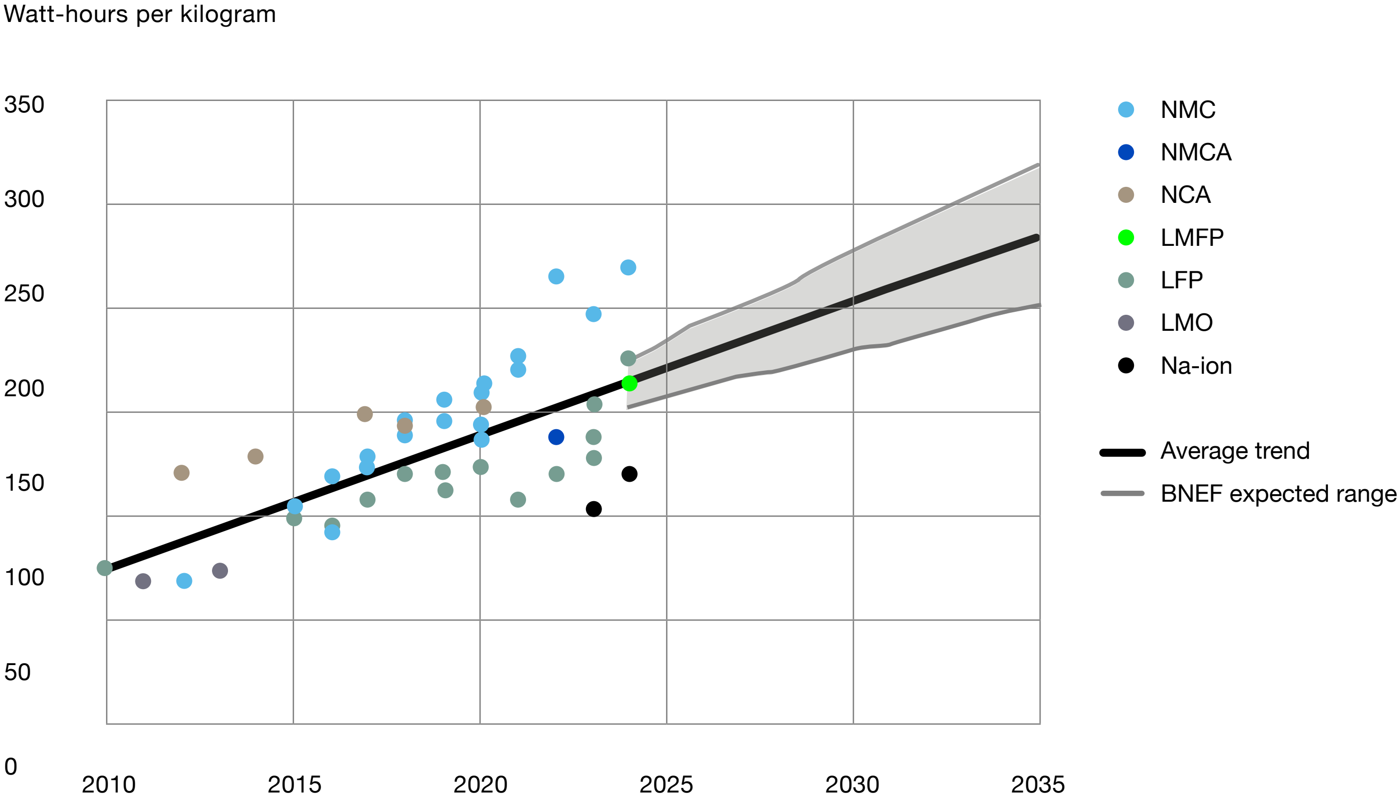
Source: BloombergNEF
Note: Commercial vehicle fuel avoided includes metropolitan buses. Fossil, bio and renewable fuel total does not include volumes consumed by ICE buses and coaches.

4.4. TECHNOLOGY

- **Cobalt will remain a key component of the battery supply chain up to 2050, despite the emergence of new battery technologies.**

The average battery pack energy density in battery-electric vehicles has more than doubled since 2010, rising 117% to 194 watt-hours per kilogram. Increasing energy density reduces the associated material and manufacturing costs and improves a vehicle's efficiency and driving range. High energy density cells pack in more kilowatt-hours per unit of weight. Cobalt rich battery chemistries have the highest energy density.

Figure 20: Historical and estimated changes to battery-pack energy density



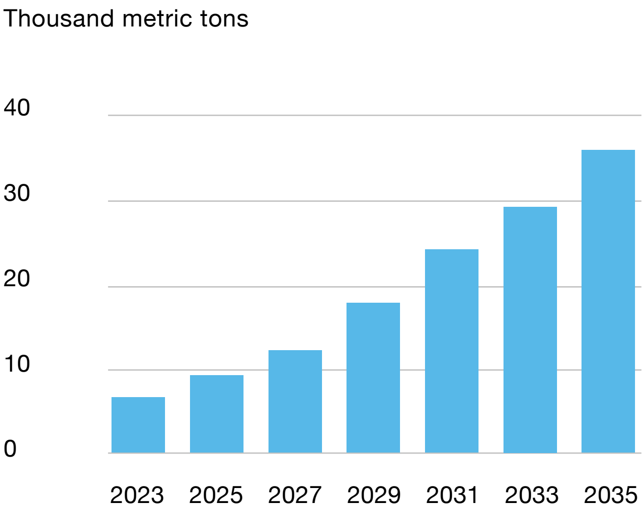
Source: BloombergNEF
Note: NMC refers to nickel manganese cobalt oxide; NMCA is nickel manganese cobalt aluminum oxide; NCA is nickel cobalt aluminum oxide; LMFP is lithium manganese iron phosphate; LFP is lithium iron phosphate; LMO is lithium manganese oxide; Na-ion is sodium ion.

BNEF expects battery chemistries that use cobalt such as the NMC to remain an integral part of future technologies. These chemistries represent the high-performance segment of the market. The rising adoption of battery electric long-haul and heavy-duty trucks will serve as a tailwind for cobalt demand. At the moment, emerging technologies like sodium-ion batteries fail to address the high energy density market.

4.5. RECYCLING

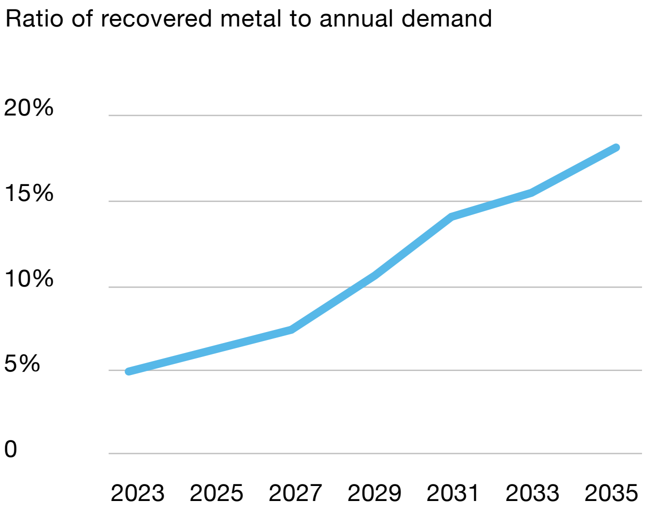
- **Lithium-ion batteries will reach the end of their initial life in electric vehicles and stationary storage projects after operating for roughly six to 15 years.**
- **Recycling can help meet up to 18% of new cobalt demand by 2035 across passenger EVs, commercial EVs, e-buses, two-/three-wheelers and stationary storage.**
- **However, this will require substantial investments today to ensure the industry is adequately prepared.**

Figure 21:
Cobalt recovered from recycling globally



Source: BloombergNEF
Note: Assumes the metal recovery rate is 95% for cobalt. The calculations are based on end-of-life batteries and new metal demand across passenger EVs, e-buses, commercial EVs, electric two- and three-wheelers and stationary storage sectors.

Figure 22:
Ratio of cobalt recovered to demand globally



Source: BloombergNEF

Battery recycling will become an important source of metal supply for the industry. It could help cathode producers that also recycle batteries offset spot price volatility and relieve resource constraints, which have been particularly pressing in the last two years.

Developing recycling technologies and building recycling capacity are now crucial to ensuring the sustainable development of the electric vehicle and stationary storage industries, and governments and the private sector are both getting into the game.

Governments are developing policies to regulate battery recycling and specify the responsibility of different market participants, while the valuable metals contained in end-of-life batteries are attracting companies across the battery value chain to invest in new recycling capacity.

China, which already leads the global battery recycling market, will account for over half of the batteries available for recycling every year through 2035. This is unsurprising, as China is the world's largest EV market in terms of cumulative sales, largest stationary energy storage market out to 2030 and has over 80% of current nameplate battery cell manufacturing capacity.

EV sales in the country took off in 2013 when the Chinese government launched subsidy incentives to promote adoption. As a result, we estimate large volumes of batteries in China reached their end of life in 2023, making over 50GWh of battery materials available.

In **Europe**, large-scale availability (over 25GWh) of end-of-life batteries is not expected until 2027. The **US** will likely top 25GWh batteries available for recycling starting in 2031.

The volume of metals available from recycling is impacted by both the quantity of batteries coming to end-of-life as well as the chemistry mix of deployed.

Lithium iron phosphate (LFP) batteries make up a large portion of near-term battery retirements, primarily because e-buses and commercial EVs in China favor this chemistry. LFP was used in some Chinese passenger EVs sold before 2017 before losing part of its market share. Starting from 2020, its use in passenger EVs in the country increased. This chemistry is also dominating the stationary storage market, as Chinese battery producers push it globally.

LFP is becoming increasingly popular in Europe and North America, although it will take longer to penetrate the recycling market in those regions, where a lack of local LFP manufacturing means low volumes of production scrap. The chemistry achieved a 15% share of the regional chemistry mix only in 2023, meaning large volumes of end-of-life cells are still at least five years away.

Lithium is the most valuable material in LFP batteries, and it is what most recyclers try to extract. In some cases, recyclers recover the precursor material to produce iron phosphate cathode, and then produce new LFP cathode active material.

Nickel manganese cobalt oxide and nickel cobalt aluminum oxide (NMC/NCA) batteries are widely used in the passenger EV market. Within the nickel-based cells, there is also a trend toward higher nickel content, specifically NMC (955) and NMC (96Ni). The volume of high-nickel batteries used in commercial EVs is expected to increase fivefold by the end of the decade due to the economies of scale from passenger EV adoption and the need for extended driving ranges in longer-haul vehicles.

Cobalt, nickel and lithium are the valuable metals to be recovered from NMC/NCA batteries. The two most common battery recycling processes are producing the salts (cobalt sulphate, nickel sulphate) for each element, and directly synthesizing NMC precursors, a mixed metal hydroxide product which is specific to each cathode.

Making precursors can help recyclers secure a higher premium for their products than producing the salts alone, although it requires a stricter qualification process from the off-takers, meaning some companies prefer to sell commodity metal salts.

[2] NMC (955) is 90% nickel, 5% manganese and 5% cobalt. NMC (96Ni) is 96% nickel with the remaining 4% a mixture of manganese and cobalt.

Lithium carbonate or hydroxide are also produced from the recycling process. In 2035, the cobalt sourced from recycled batteries could account for 18% of new demand across passenger EVs, commercial EVs, e-buses, two-/three-wheelers and stationary storage. As the chemistry mix is constantly changing, the level of demand that can be met by recycled material also evolves.

Contact us if you have any questions

Marina Demidova

Head of Communications

mdemidovaext@cobaltinstitute.org

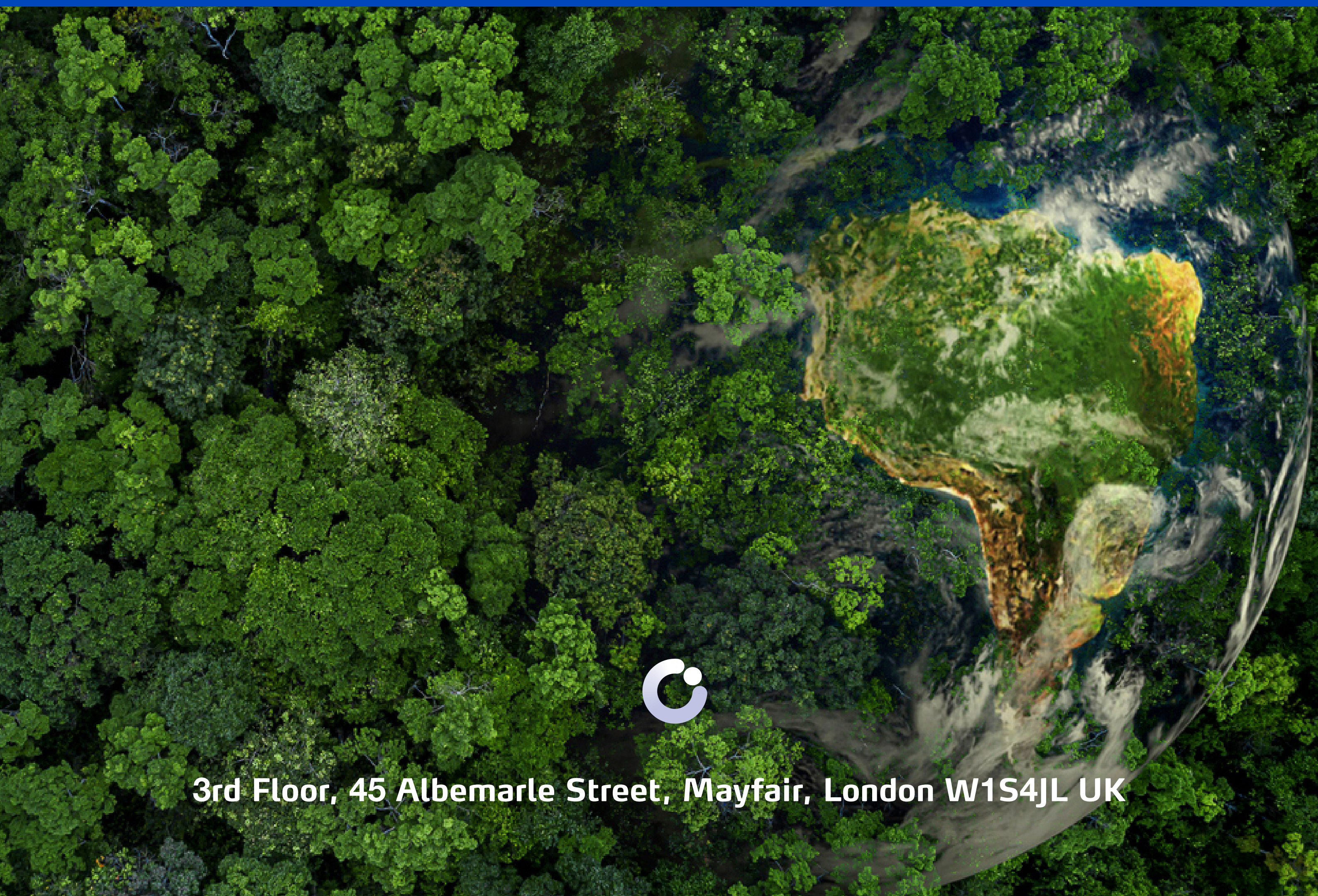
www.cobaltinstitute.org

Kwasi Ampofo

Head of Metals & Mining

kampofo1@bloomberg.net

www.bnef.com



3rd Floor, 45 Albemarle Street, Mayfair, London W1S4JL UK